THREE DIMENSIONAL VOLUMETRIC MODELING OF THE INTERNAL BRAIN STRUCTURE USING MAGNETIC RESONANCE IMAGING SLICES

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Abstract-**The conventional cross sections of the brain, provided by magnetic resonance imaging (MRI) scanners, comprise a sparse dataset of 2-D gray-level images, that is neither capable of representing the 3-D nature of the brain, nor differentiating its various component parts in a convenient way. The target of the developed work is to fuse more information from the original MRI cross sections, which leads to building a 3-D computerized color-coded model of the normal human brain. The proposed model is beneficial in many areas like medical training, radiation treatment, 3-D model matching, or volume mensuration of brain component parts. This paper presents a revision of the different methods for building 3-D brain models, along with their advantages and disadvantages. A proposed method for building a 3-D brain model is then introduced. The method consists of three stages: interpolation of the original MRI slices, segmentation of the different brain tissues, and 3-D volumetric reconstruction. The resultant model can be geometrically transformed and arbitrarily dissected. The results are shown throughout the paper. Finally, the conclusions drawn from this work, as well as possible future extensions of the work, are listed.**
***Keywords* - 3-D volumetric modeling, brain atlas, image segmentation, magnetic resonance imaging (MRI), slice interpolation**

I. INTRODUCTION

A truly 3-D feel of the brain cannot be obtained from the 2-D cross sections provided by medical scanners. Although radiologists are trained to reconstruct this picture in their minds, this is of course a difficult task for the untrained eye. So, it is of a great importance to construct a comprehensive 3-D brain atlas or model, which helps in describing the shape, configuration, and layout of brain component parts. Furthermore, for 3-D visualization of brain structures, accurate volume mensuration, radiation treatment, or 3-D model matching, a 3-D model representation of the normal human brain is an essential. With a digital brain atlas, the user is able to translate, rotate, scale, and even dissect the brain model in 3-D. The user can also visualize a certain structure from the point of view that best clarifies it. Interest in constructing a 3-D human brain model has been the focus of many researchers [1], [2], [3]. Besides, the manufacturing of new brain-imaging scanners and the vast development of computer systems combine together to start a revolution in the brain-related field of research.

In section II, the various 3-D modeling methods are reviewed. The proposed modeling method is introduced in section III. Section IV shows the different output results gained from this work. Finally, the conclusions and possible future work extensions are listed in section V.

II. 3-D CONSTRUCTION AND MODELING METHODS

There are several possible approaches for building a 3-D brain model. Some of these approaches include building a mesh-based model, a contour-based model, or a 3-D volumetric model.

Mesh-based models are concerned in extracting the iso-surface volume of interest (VOI) using certain algorithms. These algorithms use interpolative techniques, which assume continuity and smooth gradient of voxel densities [4]. The assumption clearly fails in the case of a color-coded volume. A natural solution would be to convert the volume into a binary volume, based on the index value of the structure of interest, then to isolate the surface with a threshold value of 0.5. The authors in [5] used this method for building a 3-D brain atlas. They had to use a convolution-like surface reconstruction technique to smooth the original volume. The immersion effect is a drawback of this method. It appears between surfaces of adjacent structures, and produces distorted and enlarged surfaces. So, this effect has to be minimized. Examples of other drawbacks of the mesh-based 3-D modeling are that small structures are eliminated and the resulting model is jagged.

The second approach for building a 3-D brain model is the contour-based modeling, which connects the adjacent slices forming a wireframe model. Such algorithms can be quite simply implemented, and could be easily adjusted to the color-coded images. The correlation technique is the backbone of the contour-based modeling method. Several landmarks in each slice have to be correlated and connected to their counterparts in the next one using matching vectors. The authors in [6] adopted this technique in their work. The contour-based 3-D modeling incorporates the following difficulties: anatomical correspondences between slices have to be explicitly defined, cross-over connections have to be eliminated, and the missing data between adjacent slices have to be compensated. The matter gets worse when a landmark is translated from one slice to the next one. Also, branching objects cause great difficulties.

Three-dimensional volumetric modeling is the third approach for building a 3-D brain model. In this method, a pack of horizontal slices are put one on the top of another. This method has many advantages. First, the generated models are best suited for volume rendering techniques. Second, the resultant model can be arbitrarily dissected without any difficulty. Moreover, the images of a patient, however they are acquired, can be easily registered to the model. Because this approach alleviates the disadvantages of the other ones, it is adopted in this work.

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Abstract

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III. THE PROPOSED MODELING METHOD

A volumetric method for building a 3-D model of the brain is proposed. It is based on the following steps :

1st.Interpolation of the Original Magnetic Resonance Imaging (MRI) Slices

This step assists in building an isotropic 3-D space and in representing the internal brain structure much more smoothly and accurately. Because medical imaging systems collect data slice by slice, the distance between adjacent image elements within a slice is different from the spacing between adjacent image elements in two neighboring slices. For visualization, manipulation, and analysis of such anisotropic data, they often need to be converted into data of isotropic discretization. This conversion helps in visualizing the imaged property of the structure of interest within any selected plane of arbitrary orientation [7].

The trilinear method of interpolation proved to be a good estimation method [8]. It is better than the nearest neighbor, the averaging, or the linear interpolation methods, because it uses more sample values to compute the estimate and because the distance from each sample to the interpolation point is taken into account. Higher-order interpolations than the trilinear method may create inaccurate estimates because of the assumed strict data variation among points [9]. Using the kriging interpolation method with a small number of neighborhoods produced interpolant value estimates close to the trilinear method, and got the closest match to trilinear with a neighborhood of eight voxels [8]. But it should be noted that the trilinear method is much faster than the kriging method.

In [8], the trilinear interpolation technique was applied to each pair of consecutive slices in order to obtain the in-between slice. An example of an estimated slice along with its surrounding slices, from which the estimated slice was obtained, are shown in Fig. 1. At the end of this stage, the number of slices has been doubled. The interpolation technique was then applied again, and finally, an isotropic dataset was obtained. This final dataset was then used in the following segmentation and 3-D reconstruction stages. The validation results were given in [8], which showed the superiority of the adopted interpolation technique.

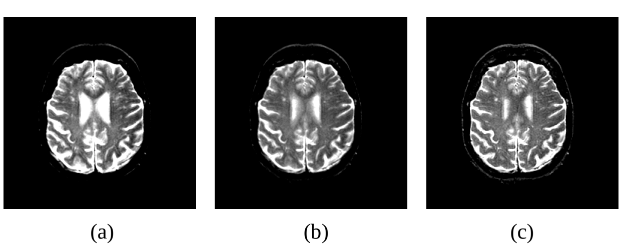


Fig. 1. The results of the interpolation stage. (a) The lower slice. (b) The in-between estimated slice. (c) The upper slice.

2nd. Segmentation of the Different Brain Tissues

This step makes the differentiation among brain tissues very easy. Brain matters, as assessed by MRI, can generally be categorized as white matter (WM), gray matter (GM), or cerebrospinal fluid (CSF). Most brain structures are anatomically defined by boundaries of these tissue classes. So, a method to classify and segment tissues into these categories is an important step in quantitative morphology of the brain. An accurate classification and segmentation technique may facilitate the detection of various pathological conditions, 3-D visualization of brain matter, model registration, radiotherapy treatment, and surgical planning [10], [11].

It has been found that feed-forward artificial neural network (ANN)-based classification and segmentation methods generally perform better than other algorithms [10], [11]. So, the advantages and capabilities of ANNs are the motivations behind the usage of an ANN-based segmentation technique in this work [12].

In [13], a three-layer feed-forward ANN is used to segment the original MRI slices into WM, GM, and CSF. Fig. 2 shows the ANN used. Firstly, a graphical user interface (GUI) environment is designed to enable the acquirement of characterizing pixels of each tissue type. This process is done once and off-line. The next step is to use these pixels as the training vectors of the ANN. The error back-propagation training technique is used with the generalized delta rule for learning. The presentation phase is then used to segment the multispectral MRI slices. The presentation phase is applied to each pixel of the slice in order to decide to which tissue it belongs. The pixel is then given a specific color representing this tissue. New color-coded images are created as shown in Fig. 3. The learning error curve, the weight and bias values of the ANN, and the validation results are found in [13].

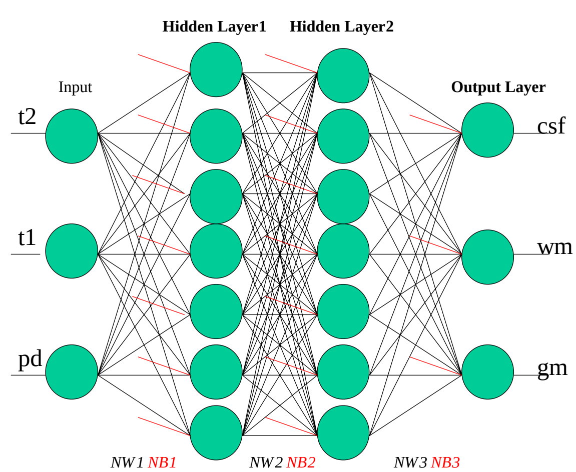
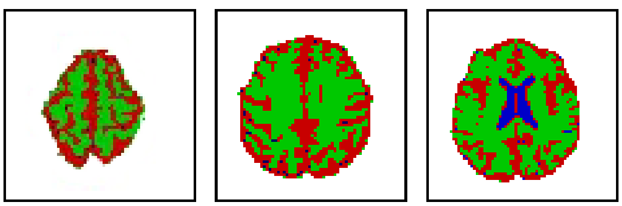


Fig. 2. The proposed ANN used to segment the brain tissues.

3rd. 3-D Volumetric Reconstruction

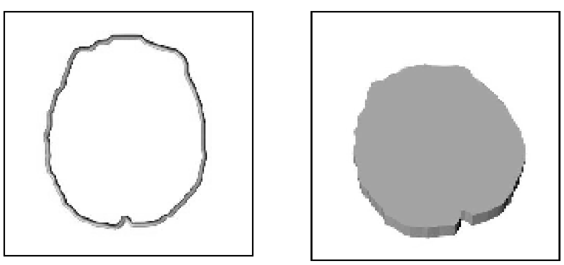
The steps of this stage can be summarized as follows:

1) The boundary (contour) of each image, like the image shown in Fig. 3(c), is traced. Some points on the contour are marked and used to build a spline that represents the contour, as shown in Fig. 4(a).
2) The curve is then capped and extruded to give it a small thickness as shown in Fig. 4(b).
3) The image in Fig. 3(c) is used to shade the slice obtained in step 2. Fig. 5 shows a complete and a cut slices.
4) The previous steps are repeated for all the axial images. The slices are put one on the top of another and then linked together to form the volumetric model.
5) The model is Blinn-shaded using two light sources, one is above and to the left of the scene, and the other is below and to the right.
6) The scene is then rendered using the scan line and the z-buffer algorithms. A thorough discussion of these algorithms is found in [14].



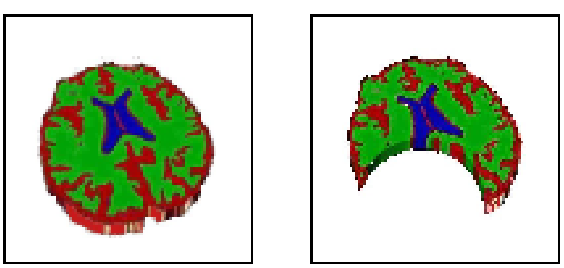
(a) (b) (c)

Fig. 3. Output segmented slices representing different axial cross-sections of the brain.



(a) (b)

Fig. 4. (a) The contour of the slice. (b) The contour is given some depth



(a) (b)

Fig. 5. (a) Complete shaded slice. (b) Shaded slice with a cut.

The following results are obtained:

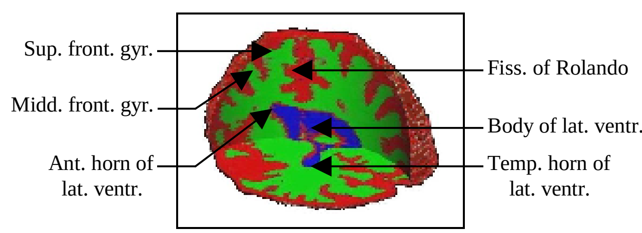
- The model can be geometrically transformed, animated, and even dissected. The results are obtained in various projections, which are helpful in studying the internal brain structure from different positions. This is done interactively, which is a great advantage of the computerized brain models.
- Several cuts are made in the model to see the internal structures of the brain. Examples of these cuts are the cylindrical and spherical cuts, shown in Fig. 6. Any other dissection can be made. The resulted images can be used to enhance the understanding of the brain anatomy or to help brain surgeons in making their decisions.
- Sagittal, coronal, and tilted slices can be obtained from the model without using the MRI scanner for an extra period of time or exposing patients to extra rays, Fig. 7.

The output results of the volumetric modeling stage have been validated by medical experts. They have been compared to the brain anatomy in textbook atlases including the Talairach-Tournoux atlas. The comparisons showed the efficiency of the proposed work.

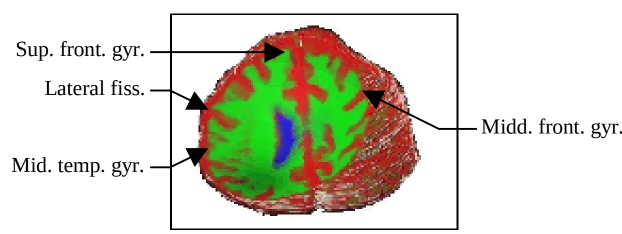
V. Discussion

The following conclusions can be drawn from this work:

- The volumetric modeling method proved to be better than other methods for building 3-D brain models.
- The proposed ANN-based segmentation method yields better results and less error rates than conventional methods. This is due to the various advantages and capabilities afforded by ANNs.



(a)



(b)

Fig. 6. The model is dissected arbitrarily to show the internal brain structure. (a) Cylindrical cut. (b) Spherical cut.

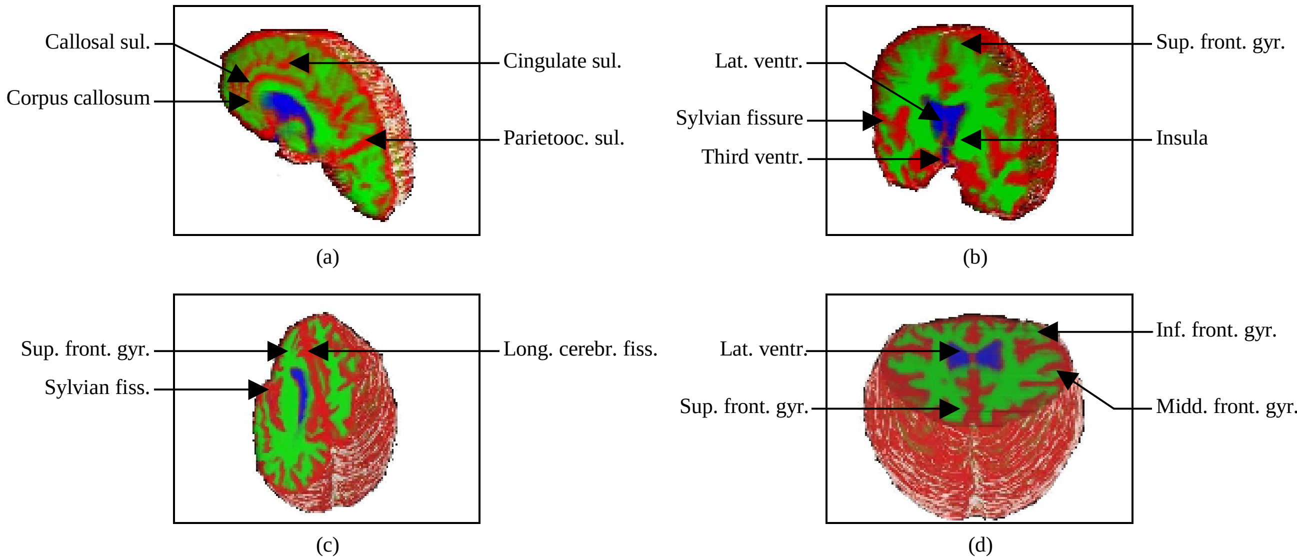


Fig. 7. (a) Sagittal slice. (b) Coronal slice. (c) Sagitto-axial slice. (d) Corono-axial slice.

- Applying the interpolation technique, to get a densely-packed dataset of brain cross sections, yields smoother and more accurate results of the 3-D modeling stage.
- Multispectral MRI images are preferred to single-echo ones, for the analysis of brain datasets, because multispectral images provide more information at the voxel site than single-echo images.

There are several directions to extend the proposed work :

- The cerebral cortex can be modeled and included in the proposed model.
- The brain blood vessels and the basal ganglia can be included in the proposed model.
- Functional images of the brain can be registered to the proposed model.
- The proposed model can be used for studying the aging factor and brain pathology development.

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